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TECHNICAL REPORT 8904

SHOWER WATER RECYCLE
I. RAW SHOWER WATER CHARACTERIZATION AND TREATMENT

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February 1989

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Shower wastewaters collected at Camp Edwards, MA, on three different days were characterized in terms of physical, chemical and microbiological parameters, and were found to be similar to shower wastewaters from earlier studies. Camp Edwards shower waters were treated with aluminum sulfate and powdered activated carbon, and were filtered through a bench-scale diatomaceous earth filter designed to simulate the EARDLator. The treated shower water has been characterized and evaluated for potential recycle.

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PREFACE

Field studies at Camp Edwards, MA were assisted by MAJ Walter M. Tyler, Engineering Resources Manager, and CPT Edward L. Pesce, Facilities Manager, Connecticut Army National Guard. Chemical analyses were performed under the direction of Dr. Steven H. Hoke of the U.S. Army Biomedical Research and Development Laboratory. Dr. Elizabeth P. Burrows performed GC/MS analyses. Microbiological tests were conducted under the direction of Ms. Linda L. Hildebrand of the U.S. Army Medical Research Institute of Infectious Diseases.

INTRODUCTION

This study relates to health concerns arising from the need of the field Army to conserve and reuse water in regions of short supply. The Army and others have recognized that shower facilities for personnel may impose the greatest demand for high quality nonpotable water in the field. Treatment of shower wastewater for reuse could reduce this requirement by 80 percent or more, and at the same time substantially reduce the problem of wastewater disposal.

The relationship of health of field personnel to frequency of bathing is obscure; this, and questions concerning the safety of shower water reuse, will be addressed in a future report[1]. In the Mediterranean theater of operation during World War II, skin diseases caused little loss of trained troops for duty[2]. Those who were hospitalized most often suffered from _Staphylococcus_, _Streptococcus_ or fungus infections caused by a lack of facilities for personal hygiene. In Vietnam the yeast _Candida albicans_ was found to be a particular problem due to the extremely hot and humid environment[3].

In the study reported herein, the U.S. Army Biomedical Research and Development Laboratory (USABRDL) has characterized raw shower water in the field and has performed bench-scale tests of the ERDLator system to determine the effectiveness of this type of treatment train for processing shower water for recycle. Shower waters from three different groups of field soldiers were sampled; and the data were averaged to create a profile of the physical, chemical, and microbiological characteristics of military shower water.

Characterization of the wastewaters from military field laundries, showers, kitchen units, and a possible treatment train were addressed in 1973 at Camp A.P. Hill by Lent and Ross of the U.S. Army Mobility Equipment Research and Development Center (MERDC)[4]. This study examined utilization of the 420 gph ERDLator system for the treatment of these wastewaters for discharge and possible reuse. In 1986, the U.S. Army Construction Engineering Research Laboratory (USACERL)[5] tested a shower wastewater recycling system based on the 420 gph ERDLator at the Virginia Military Institute (VMI). This system used a batch method of treatment, and the water was recycled and reused several times. Neither the MERDC nor the USACERL study addressed microbiological characteristics.

OBJECTIVES

The overall objectives of the USABRDL study were to characterize actual field shower water and to evaluate the effectiveness of a bench-scale treatment train in treating shower water for recycle. The specific objectives were:

a. To document the physical and chemical makeup of shower water with respect to pH, turbidity, conductivity, alkalinity, hardness, total organic carbon (TOC), chemical oxygen demand (COD), total solids (TS), total dissolved solids (TDS), chlorine demand, and presence of hazardous organic contaminants.

b. To examine shower water for microbial content, *viz*. total coliforms, *Pseudomonas aeruginosa*, *Staphylococcus aureus*, and *Candida albicans*.

c. To determine the efficiency of the bench-scale treatment train, consisting of powdered activated carbon adsorption, aluminum sulfate coagulation, flocculation, filtration, and disinfection, in dealing with chemical and microbiological parameters of shower water, and to determine if the treated water meets the standards of TB MED 577 for reuse[6].

d. To examine treated samples for the presence of treatment by-products.

e. To assess the suitability of the bench-scale treatment train as a model for the ERDLator by comparison of results, where possible, with those obtained by MRDEC and USACERL.

EXPERIMENTAL PROCEDURES AND MATERIALS

Groups Sampled

18 NOV 87 - Sample events 1-4 involved the use of troops from A COMPANY 1-102 INF. Connecticut Army National Guard, (CANG). Sample events 5-8 utilized troops from B COMPANY 1-102 INF. CANG. These troops were without showers 10-14 days. All showers were limited to 4 minutes each.

16 AUG 88 - Sample events 1-10 utilized troops from C COMPANY 458th ENGR. BN. U.S. Army Reserve. These troops were without showers for 5-7 days. Shower time was unlimited and determined by the individual.

22 AUG 88 - Sample events 11-16 utilized troops from A,B COMPANY 101st ENGR. BN. Massachusetts Army National Guard. These troops were on day work and had showered the night before. Shower time was unlimited.

Methods and Equipment

Standard wastewater parameters. Total organic carbon was determined with a Beckman model 915 B Tocamaster TOC analyzer. The pH was determined with an Extech model 609 pH digital meter. Conductivity was determined with a Presto-Tek model DP-03 conductivity meter. Turbidity was determined with a Hach model 2100 A turbidimeter. Chemical oxygen demand was determined using method 410.4 in Methods for Chemical Analysis of Water and Wastewater, EPA 600 4-79-020. (For reasons not established, COD values for both treated and untreated shower wastewaters were highly variable and inconsistent.) Alkalinity was determined using Method 309 B from Standard Methods (ed. 15)[7]. Hardness was determined using Method 309 B EDTA titrimetric method from Standard Methods (ed. 14). Total solids were determined using method 209 A (total residue dried) from Standard Methods (ed. 15). Total dissolved solids were determined using Method 209 B (total filterable residue) from Standard Methods (ed. 15). Chlorine demand tests were performed using both a DPD kit and a Fisher-Porter model 17T1010 Chlorine Titrator.

Chlorination by-products. A 50-ml portion of each sample was saturated with sodium chloride and extracted with two 4-ml portions of chloroform (Burdick and Jackson GC/MS grade). The chloroform extracts were dried over magnesium sulfate, evaporated, and the residues were dissolved in acetone for analysis in electron impact mode. Instrumentation was a Hewlett-Packard 5985B GC/MS equipped with a 25-m x 0.2-mm ID DB-5 capillary column interfaced directly to the source. The GC oven was kept 2 minutes at 100°, programmed to 250° at 20° per minute and held for a total analysis time of 15 minutes.

Bacteriological testing. Samples for total coliform count were sent to the Mid-Atlantic Regional Laboratory, Rockville, MD., for analysis by membrane filtration (Method 909 A, Standard Methods, ed. 14). Colony counts for *S. aureous*, *P. aeruginosa* and *C. albicans* were performed by the U.S. Army Research Institute of Infectious Diseases, Fort Detrick, MD, by plating on sheep's blood agar and MacConkey's agar.

Sample Collection

There were three shower heads in each area sampled, which collectively delivered approximately 12-13 liters per minute. The number of individuals showering at one time was determined by availability of the various squads and varied from two to three individuals, each of whom showered for 3 to 10 minutes, 5 minutes being typical. Continuous samples were collected from the barracks showers. The first step was to remove the floor drain covers. Then a wooden stick with a wooden semicircle attached at the bottom was lowered into the drain to create a small pool for two silicone tubes (.261 inches inside diameter) to draw from (Figure 1). To avoid any chance of electrical shock all sample tubing was run from the shower stall area to draw pumps, which were mounted well off the floor in a small dressing area next to the shower. All the electrical lines were also grounded. Masterflex pumps, model WZ1R057 (Cole-Parmer Instrument Company, Chicago ,IL) delivered 1.5 liters per pump when operated at a maximum setting of 600 RPM (Figure 2).

Simulated Bench Scale Treatment

1. Shower water (8 L) was measured into a 5 gallon glass jar.

2. Powdered activated carbon (Norit A, 1 mg/l) was added and rapidly mixed for 15 minutes (Figure 3). This dose duplicated the dose used in the USACERL[5] study.

3. A stock solution of aluminum sulfate hydrate (30 g/l, 4 ml) was added and mixed rapidly for 10-15 seconds.

4. The mixer was then adjusted to 35 rpm, and the mixture was allowed to flocculate for 20 minutes.

5. The mixer was shut off and gravity sedimentation was allowed to occur (Figure 4).

Figure 1. Sampling device

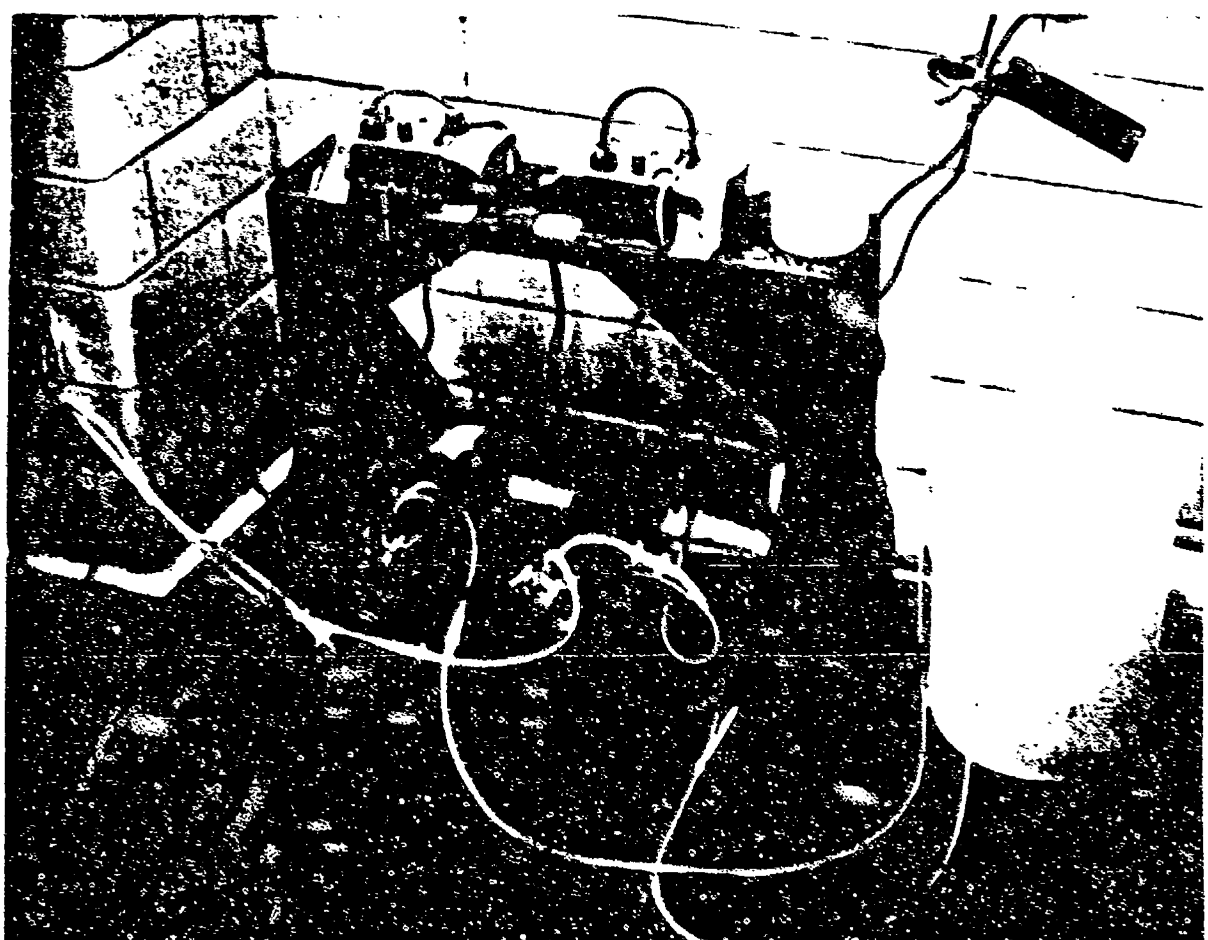

Figure 2. Sampling pumps

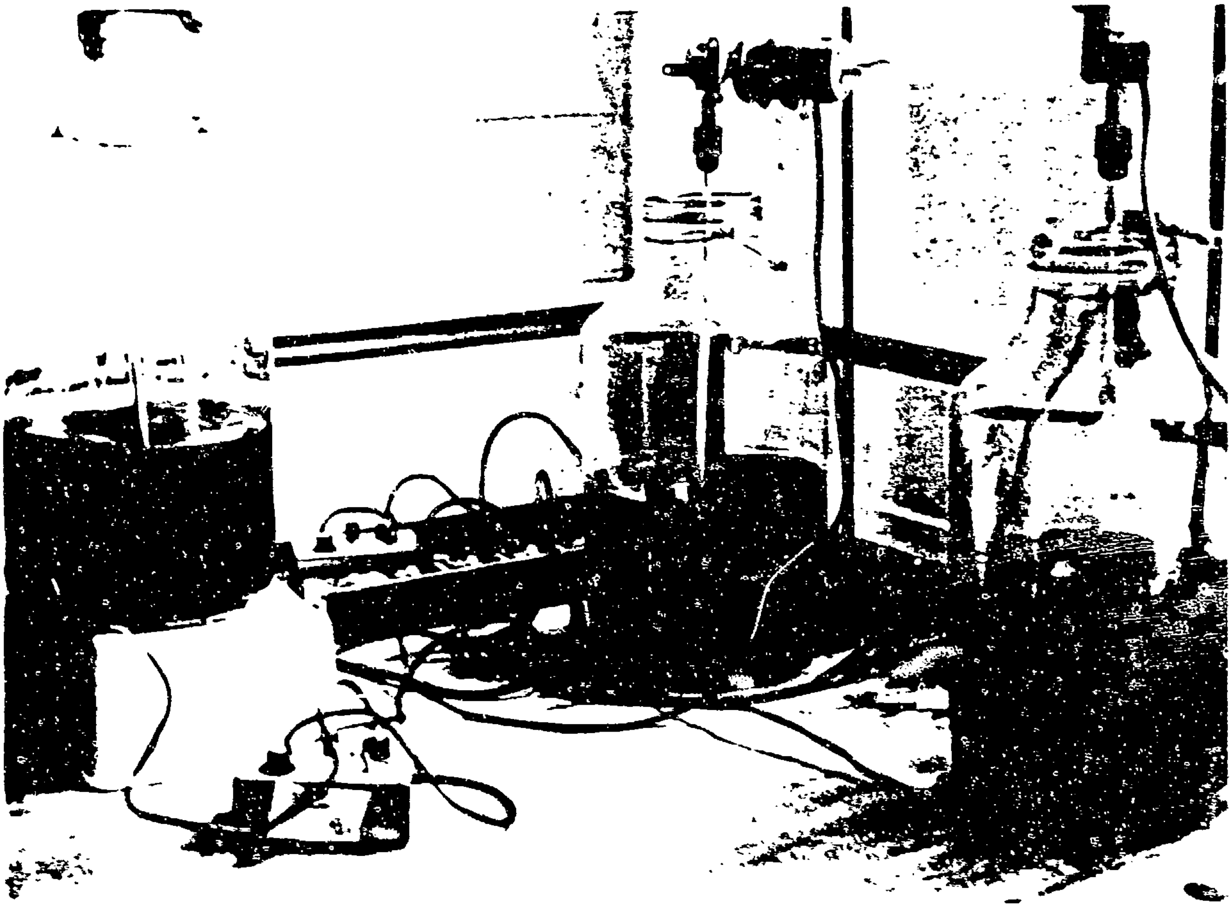

Figure 3. Powdered activated carbon treatment of wastewater during mixing

Figure 4. Chemical treatment of wastewater during sedimentation

6. The supernatant was drawn off and collected using a small peristaltic pump.

7. A diatomaceous earth filter was prepared by first placing Whatman No. 4 filter paper in an 18 cm Buchner funnel and then pouring a slurry made of distilled water and diatomaceous earth into the funnel, giving a final bed depth of 2-3 inches (5-7.5 cm).

8. The supernatant from Step 6 was drawn through the filter bed using a side arm flask fitted to a small vacuum pump.

9. As a final step the filtered supernatant was disinfected by addition of 1000 mg/l stock chlorine solution as required to yield a final concentration of 5 mg/l of free available chlorine (FAC).

10. The samples then drawn for testing are referred to as "treated" in the data tables.

RESULTS AND DISCUSSION

Wastewater Characteristics

Characteristics of Camp Edwards shower wastewater, presented in Appendix Tables A1 through A6 and summarized in Table 1, appear to be uniform and independent of troop history, i.e. wastewater parameters are approximately the same for soldiers who last showered two weeks earlier and those who last showered 24 hours earlier. From this we surmise that typical field shower wastewater will have a TOC of 30 to 40 mg/l in the absence of water conservation practices, or 43 to 58 mg/l of soap, corresponding to 1-2 g of soap consumed per soldier per shower. Wastewater from Camp A.P. Hill (for which water consumption was not reported) was about half as strong in terms of TOC. Two batches of initial wastewater from VMI [10.6 gal (40 L)/shower] had TOC levels of 225 mg/l and 22.5 mg/l, respectively; the source of variability is not explained. Turbidity, the other significant indicator of shower wastewater quality, fell in the range of 50-80 NTU for all groups except the first VMI batch, for which it was very high.

Candida albicans, _P. aeruginosa_, and _S. aureus_ were chosen as the test organisms for the USABRDL studies because they are commonly found in the mouth, nose, and throat[8] and have shown up in field units in the past as skin pathogens[2,3]. Total coliform counts were also checked since water quality is based on this parameter. Microbiological characteristics of the Camp Edwards shower wastewater (Table A7) were unexceptional except for the absence of _P. aeruginosa_ and _C. albicans_. The standard plate count exceeded 30,000 CFU/ml, coliforms exceeded 100 CFU/100 ml, and _S. aureus_ commonly fell in the range of $1\text{-}5 \times 10^5$ colonies/ml. The chlorine demand of this wastewater (Table A8) was relatively low.

GC/MS analysis of the Camp Edwards wastewater revealed only the expected even-numbered long chain fatty acids, n-C_{10} through n-C_{18}. There were no chlorination by-products of low volatility; trihalomethanes would not have been detected by this procedure.

TABLE 1. AVERAGE SHOWER WASTEWATER CHARACTERISTICS

Site	TOC mg/l	Turbidity NTU	Hardness mg/l as $CaCO_3$	Alkalinity mg/l as $CaCO_3$	pH	TDS mg/l	Cl demand mg/l
Camp Edwards							
18 Nov 87	38	69	50	67	7.4	137	2.7
16 Aug 88	34	65	43	48	6.7	130	
22 Aug 88	30	49	52	52	7.0	125	
Camp A.P. Hill[a]	15	59	18	136	6.8	175	
VMI							
Batch 1[b]	225	370			7.9		
Batch 2[b]	22	79			7.4		

a. Includes lavatory sink wastes
b. Wastewater from fir[illegible]e

Wastewater Treatment

Procedures developed by USABRDL, MRDEC and USACERL for treatment of shower wastewater were similar, but differed in some important respects. Both MRDEC and USACERL employed the diatomaceous earth (DE) filter of a 420 gph ERDLator, while USABRDL used a bench-top filter. The USACERL study involved 8 to 11 stages of treatment and reuse, while MERDC and USABRDL, who used field troops, treated but did not reuse the wastewater. USABRDL used aluminum sulfate as flocculant; MRDEC used a cationic polymer; USACERL studies used both cationic and anionic polymers and in addition used sulfuric acid to adjust the pH of the wastewater. For all three studies, powdered activated carbon (PAC) was used for removal of soluble organics.

Characteristics of treated wastewater (Tables A4 through A6) are summarized in Table 2 and Figures 5 through 10. TOC removals at Camp Edwards and Camp A.P. Hill averaged 53-86 percent, and the turbidity was consistently below the upper limit of 1 NTU recommended for reuse of shower water (Table 3). TOC removals reported for the VMI studies were widely variable, but eventually stabilized at 80-85 percent in later cycles; the turbidity occasionally exceeded 1 NTU, but never approached the upper limit of acceptability of 5 NTU. The product water pH in both the USABRDL and USACERL studies occasionally fell below the standard of 6.5, but never exceeded the upper limit established to assure adequate disinfection. As expected, the TDS increased in both the USABRDL and USACERL studies due to addition of sulfate, but for reasons unknown to us, total hardness increased after treatment in all studies, even exceeding the maximum limit of 500 mg/L for later cycles in the USACERL study. Alkalinity was substantially diminished in both the USABRDL and USACERL studies, reflecting the addition of acidic materials.

TABLE 2. AVERAGE TREATED WASTEWATER CHARACTERISTICS

Parameter	Camp Edwards 16 Aug 88	Camp Edwards 22 Aug 88	Camp A.P. Hill	VMI[a] Batch 1	VMI[a] Batch 2
TOC, mg/L	4.9	14	4	15-26	2.5-32
Turbidity, NTU	<1	<1	<1	<1-1.4	<1-1.2
Hardness as $CaCO_3$, mg/L	70	64	24	242-496	256-661
Alkalinity as $CaCO_3$, mg/L	9	23	124	46-271	31-222
pH	5.7	6.8	7.3	4.9-6.7	5.5-7.5
TDS, mg/L	165	155	170	494-1524	438-1682
Chlorine demand, mg/L	2.6	2.7			

a. Range of parameters for all treatment cycles

The chlorine demand did not change measurably upon treatment of the shower wastewater at Camp Edwards (Tables A9 and A10). This is significant because it indicates that chlorine demand results from soluble materials in the waste, such as alcohol, which are not removed by PAC. (The demand of the source water was essentially nil.) However, GC/MS analysis of the treated wastewater showed the presence of phthalates and fatty acids, but no chlorinated organics. (Again, volatile chlorinated organics, such as trihalomethanes, would not have been detected.) Microbiological tests showed no growth of *P. aeruginosa*, *S. aureus*, or *C. albicans*, and only a few of the standard plate count or coliform tests were positive (Table A7).

TABLE 3. RECYCLED WATER STANDARDS[a]

Constituent	Maximum acceptable limit
pH	6.5 - 7.5
Turbidity	5 NTU[b]
Hardness	500 mg/L
Free available chlorine[c]	5 mg/L, >20° 10 mg/L, <20°

a. Reference 6
b. Maximum recommended, 1 NTU
c. Target residuals with a minimum contact time of 30 min.

CONCLUSIONS AND RECOMMENDATIONS

Shower Wastewater Characteristics

The three shower periods studied at Camp Edwards gave essentially the same wastewater characteristics, which were similar to those from studies at Camp A.P. Hill and VMI. Shower wastewater from Fort Detrick or other local barracks which exhibits the following range of parameters would be suitable to use for testing equipment, which would eliminate the need for field trips in the future.

TOC: 30-40 mg/L

Turbidity: 60 to 70 NTU

pH: 6.5-8

TDS: 125-175 mg/l

Microorganisms: Present at measurable levels

Shower Wastewater Treatment for Reuse

The bench scale treatment train described is able to reproduce the results of earlier full scale studies. Results suggest that removal of chemical and microbiological contaminants of shower wastewater can be achieved using existing Army treatment equipment. Reuse of this water for showering in an arid environment is technically plausible; however, the acute and chronic health considerations from the use of treated shower water have not been fully evaluated.

REFERENCES

1. Nelson, D.W., W.D. Burrows and S.A. Schaub. 1989. Shower Water Tecycle II. Health Considerations. U.S. Army Biomedical Research and Development Laboratory, Fort Detrick, Frederick, MD. Technical Report 8905

2. Anderson, R.S. and P.W. Havens, Jr., eds. 1968. Infectious Diseases and General Medicine. Internal Medicine in World War II, Vol. III. Office of The Surgeon General, Department of the Army, Washington, D.C.

3. Allen, A.M. 1977. Skin Diseases in Vietnam 1965-1972. Internal Medicine in Vietnam, Vol. I. Office of The Surgeon General and Center of Military History, U.S. Army, Washington, D.C.

4. Lent, D.S. and R.G. Ross. 1973. Treatment of Waste-waters from Military Field Laundry, Shower, and Kitchen Units. Army Mobility Equipment Research and Development Center, Fort Belvoir, VA. Report 2061, AD-765483.

5. Sholze, R.J., J.T. Bandy, D.K. Jamison, J.A. Morgan, V.J. Ciccone, W.P. Gardiner, and E.D. Smith. 1987. Full-Scale Test Program for a Shower Wastewater Recycling System: Technical Evaluation. U.S. Army Corps of Engineering Research Laboratory. CERL-IMT, Champaign, IL. USACERL Interim Report N-87/06.

6. TB MED 577. March, 1986. Occupational and Environmental Health, Sanitary Control and Surveillance of Field Water Supplies. Department of the Army Technical Bulletin, Headquarters, Department of the Army, Washington, DC

7. American Public Health Association. 1976. Standard Methods for the Examination of Water and Wastewater, 14th Ed. Washington, DC

8. Benson, A.S., Ed. 1985. Control of Communicable Diseases in Man, 14th Ed. The American Public Health Association, Washington DC

APPENDIX A: DATA

TABLE A1. PROPERTIES OF RAW COMPOSITE SHOWER WATER, 18 NOV 1987

Sample	Number	pH	Turbidity NTU	Conductivity micromhos
Raw water	C-1	7.58	78	170
	C-2	7.58	56	200
	C-3	7.45	80	190
	C-4	7.58	90	220
	C-5	7.35	80	200
	C-6	7.28	84	220
	C-7	7.28	40	190
	C-8	7.35	47	210
	Averages:	7.40	69.4	200
	Std. dev:	0.134	18.8	16.9

TABLE A2. PROPERTIES OF WASTEWATER COMPOSITE SAMPLES, 18 NOV 1987, CONT.

Sample	Alkalinity mg/l $CaCO_3$	Hardness mg/l $CaCO_3$	TOC ppm C	COD mg/l	TS mg/l	TDS mg/l
C-1	37.0	48	40.4	127	184.75	151.25
C-2	68.4	52	28.2	97	159.75	48.00
C-3	91.2	53	36.5	161	210.50	155.25
C-4	68.4	45	57.2	280	255.25	156.50
C-5	85.5	42	32.5	212	249.25	159.00
C-6	74.1	45	54.5	195	246.50	173.50
C-7	45.6	55	24.1	110	172.50	123.25
C-8	68.4	53	32.2	144	204.75	128.75
Averages:	67.3	49.1	38.2	165.75	210.40	136.90
Std. dev:	18.29	4.764	11.96	60.804	36.870	39.480
Tapwater 1[a]	59.5	56	1.75	-	108.00	107.00
2	51.3	59	1.71	-	114.25	229.25[b]
3	74.0	55	2.27	-	122.00	121.00
4	68.4	55	2.10	-	123.25	118.75
Averages:	63.3	56.2	1.96	-	116.90	144.00
Std. dev:	9.98	1.89	0.272	-	7.131	57.164

a. Samples were taken from 4 different shower heads in the same barracks.
b. Not included in average.

TABLE A3. PROPERTIES OF RAW AND TREATED SHOWER WATER, 16 AUG 1988

Sample	Number	pH	Turbidity NTU	Conductivity micromhos
Raw water	1	6.72	75	180
	2	6.72	45	190
	3	6.70	34	180
	4	6.64	38	180
	5	6.64	65	165
	6	6.52	60	170
	7	6.65	82	160
	8	6.63	80	180
	9	6.67	77	200
	10	7.04	94	180
	Averages:	6.69	65	179
	Std. dev:	0.135	20.3	178.5
Treated water	1	5.59	0.20	290
	2	5.63	0.42	230
	3	5.68	0.12	220
	4	5.82	0.24	220
	5	5.76	0.10	240
	6	5.70	0.14	230
	7	5.78	0.16	270
	8	5.67	0.10	250
	9	5.80	0.10	280
	10	5.81	0.34	270
	Averages:	5.724	0.192	250
	Std. dev:	0.081	0.111	25.8
Tapwater		7.10	0.91	140

TABLE A4. PROPERTIES OF RAW AND TREATED SHOWER WATER, 16 AUG 1988, CONT.

Sample		Alkalinity mg/l $CaCO_3$	Hardness mg/l $CaCO_3$	TOC mg/l C	COD mg/l	TS mg/l	TDS mg/l
Raw water	1	45.6	46.2	26.2	136	248.75	124.75
	2	45.6	53.0	30.0	90	198.75	140.75
	3	45.6	54.4	13.1	[illegible]	187.25	104.75
	4	42.8	54.0	25.1	87	179.75	108.00
	5	51.3	50.4	39.2	139	235.50	171.00
	6	48.5	51.8	23.7	91	158.50	127.75
	7	45.6	45.6	28.1	226	200.00	133.50
	8	48.5	50.0	54.1	200	221.00	133.00
	9	48.5	47.2	45.9	190	243.25	151.50
	10	54.2	43.2	59.4	257	225.50	103.25
Averages:		47.6	49.6	34.5	147.2	209.80	129.80
Std. dev:		3.31	3.86	14.72	67.86	29.683	21.472
Treated water	1	22.8	63.0	7.92	285	265.25	195.75
	2	20.0	86.0	6.01	15	310.00	200.25
	3	20.0	69.0	4.14	189	167.00	44.50
	4	17.1	71.0	5.28	25	157.50	158.50
	5	20.0	86.0	4.76	22	142.50	161.75
	6	17.1	68.0	5.80	32	151.25	178.00
	7	20.0	62.0	2.59	20	134.75	160.50
	8	17.1	65.6	3.73	23	150.25	153.75
	9	17.1	64.4	4.97	28	165.75	169.00
	10	17.1	63.6	3.83	23	149.50	229.75
Averages:		18.8	69.9	4.9	66.2	179.40	165.20
Std. dev:		2.01	8.96	1.48	92.93	58.820	48.632
Tapwater		37.1	53.0	5.20	BDL	91.50	110.50

TABLE A5. PROPERTIES OF RAW AND TREATED SHOWER WATER, 22 AUG 1988

Sample	Number	pH	Turbidity NTU	Conductivity micromhos
Raw water	11	6.83	77	175
	12	6.90	25	170
	13	7.27	69	170
	14	7.17	44	180
	15	7.00	45	180
	16	6.93	33	175
	Averages:	7.02[b]	48.8	175
	Std. Dev.	0.170	20.28	4.47
Treated water	11	6.81	0.15	240
	12	6.78	0.05	220
	13	6.85	0.15	240
	14	6.60	0.15	230
	15	6.71	0.15	230
	16	6.80	0.18	240
	Averages:	6.76	0.138	233.3
	Std. dev:	0.090	0.045	8.16
Tapwater		6.95	0.44	140

TABLE A6. PROPERTIES OF RAW AND TREATED SHOWER WATER, 22 AUG 1988, CONT.

Sample	Alkalinity $CaCO_3$	Hardness $CaCO_3$	TOC mg/l C	COD mg/l	TS mg/l	TDS mg/l
Raw water						
11	51.3	52.0	59.1	191	184.75	128.00
12	62.7	54.0	22.9	16	135.25	103.25
13	45.6	60.0	29.3	BDL[a]	126.75	172.00
14	51.3	52.0	20.0	BDL	189.50	124.50
15	51.3	32.0	22.7	BDL	148.75	127.50
16	51.3	60.0	26.8	20	145.00	98.50
Averages:	52.25	51.67	30.13	-	155.00	125.62
Std. dev:	5.604	10.309	14.568	-	23.814	26.067
Treated water						
11	51.3	56.0	14.0	BDL	169.50	158.50
12	17.1	68.0	14.1	BDL	151.00	158.50
13	22.8	60.0	9.75	BDL	156.00	151.50
14	17.1	68.0	12.6	BDL	124.00	151.75
15	11.4	62.0	17.5	BDL	153.50	148.50
16	17.1	68.0	16.5	BDL	157.75	160.75
Averages:	22.8	63.67	14.07	-	151.96	154.92
Std. dev:	14.42	5.125	2.775	-	15.117	4.951
Tapwater	11.4	72.0	17.9	BDL	106.00	117.50

a. BDL = below detection limit.

TABLE A7. RAW AND TREATED SHOWER WATER SAMPLES: MICROBIOLOGICAL DATA

Sample	Std Plate CFU/ml	Coliforms CFU/100ml	*P. aeruginosa*	*S. aureus*	*C. albicans*
			colonies/ml x 10^{-5}		
16 Aug 88: Raw					
1	>30,000	>100	NI[a]	1.0-1.5	NI
2	>30,000	>100,000[b]	NI	~3.0	NI
3	>30,000	>100	NI	~0.002	NI
4	>30,000	>100	NI	2.0-2.5	NI
5	>30,000	>100	NI	~3.0	NI
6	>30,000	>100	NI	2.5-3.0	NI
7	>30,000	>100	NI	2.0	NI
8	>30,000	>100	NI	~1.0	NI
9	>30,000	>100	NI	~1.0	NI
10	>30,000	>100	NI	~3.0	NI
16 Aug 88: Treated					
1	<1.0	<1.0	NI	NI	NI
2	>30,000	>100	NG[c]	NG	NG
3	<1.0	<1.0	NG	NG	NG
4	<1.0	<1.0	NG	NG	NG
5	<1.0	<1.0	NG	NG	NG
6	<1.0	<1.0	NG	NG	NG
7	<1.0	<1.0	NG	NG	NG
8	1500	<1.0	NG	NG	NG
9	>30,000	<1.0	NG	NG	NG
10[d]	>30,000	<1.0	NG	NG	NG
Tapwater	47.0	<1.0	NG	NG	NG
22 Aug 88: Raw					
11	>30,000	>100	NI	~5.0	NI
12	>30,000	>100	NI	~5.0	NI
13	>20,000	33.0	NI	~2.0-2.5	NI
14	>30,000	>100	NI	~0.5-1.0	NI
15	>30,000	>100	NI	~1.0	NI
16	>30,000	46.0	NI	~0.5-1.0	NI
22 Aug 88: Treated					
11	65.0	<1.0	NG	NG	NG
12	124.0	<1.0	NG	NG	NG
13	<1.0	<1.0	NG	NG	NG
14	<1.0	<1.0	NG	NG	NG
15	<1.0	<1.0	NG	NG	NG
16	<1.0	<1.0	NG	NG	NG
Tap	-	-	NG	NG	NG

a. NI = none indicated.
b. Value not used in computing average.
c. NG = no growth.
d. Sample had high turbidity.

TABLE A8. CHLORINE DEMAND OF WASTEWATER COMPOSITE SAMPLES, 18 NOV 1987

Sample	Dose stock soln, ml[a]	Eff. dose mg/l	FAC(30 min.) mg/l	Cl Demand mg/l	Avg Demand & Std.Dev.
C-1	1.80	4.29	1.10	3.19	AVG.=3.33
	2.40	5.71	2.05	3.66	S.D.=0.284
	3.00	7.14	4.00	3.14	
C-2	1.80	4.29	2.40	1.89	AVG.=1.05
	2.40	5.71	4.90	0.81	S.D.=0.753
	3.00	7.14	6.70	0.44	
C-3	1.20	2.85	0.40	2.45	AVG.=2.47
	1.80	4.29	1.45	2.84	S.D.=0.365
	2.40	5.71	3.60	2.11	
C-4	3.00	7.14	1.20	5.94	AVG.=6.76
	4.20	10.00	2.40	7.60	S.D.=0.830
	5.40	12.85	6.10	6.75	
C-5	1.80	4.29	1.70	2.59	AVG.=2.15
	2.40	5.71	3.50	2.21	S.D.=0.478
	3.00	7.14	5.50	1.64	
C-6	1.80	4.29	1.15	3.14	AVG.=3.71
	2.40	5.71	1.45	4.26	S.D.=0.560
	3.00	7.14	3.40	3.74	
C-7	1.80	4.29	4.10	0.19	AVG.=0.06
	2.40	5.71	7.10	0.00	S.D.=0.110
	3.00	7.14	9.60	0.00	
C-8	1.80	4.29	2.00	2.29	AVG.=1.95
	2.40	5.71	4.10	1.61	S.D.=0.481
				OVERALL	AVG.=2.70
					S.D.=2.018

a. Stock chlorine solution used equaled 476.2 mg/l.

TABLE A9. CHLORINE DEMAND KINETICS FOR TREATED SHOWER WATER, 16 AUG 1988

Sample	Number	Free available chlorine, mg/l[a] 10 min	20 min	30 min	Chlorine demand mg/l
Treated water[b]	1	2.6	2.3	1.6	3.2
	1	2.5	2.7	1.4	3.4
	2	2.3	2.0	1.7	3.1
	2	2.4	2.0	1.8	3.0
	3	3.2	3.2	3.0	1.8
	3	3.0	3.0	3.0	1.8
	4	2.4	2.3	2.6	2.2
	4	2.7	2.4	2 7	2.1
	5	2.0	1.9	1.9	2.9
	5	2.0	2.0	2.0	2.8
	6	1.1	0.7	0.54	4.3
	6	1.0-1.5	0.6-0.8	.4	4.4
	7	3.8	3.6	3.3	1.5
	7	3.5	3.5	3.0	1.8
	8	2.6	3.1	2.9	1.9
	8	2.0-2.5	2.5-3.0	3.0	1.8
	9	1.3	2.1	2.2	2.6
	9	1.5	2.5	2.5	2.3
	10	2.9	3.1	2.5	2.3
	10	2.5	3.0	2.5	2.3
Average chlorine demand					2.6
Std. dev.					0.814
Tapwater		4.6	4.7	4.9	0
		4.5	5.0	5.0	0

a. Stock solution (0.6 mL) was added to each sample, yielding an actual dose of 4.8 mg/l.
b. For each sample pair the first determination of chlorine demand was by means of the Fisher-Porter titrator and the second by use of the DPD method.

TABLE A10. CHLORINE DEMAND KINETICS FOR TREATED SHOWER WATER, 22 AUG 1988

Sample	Number	Free Available Chlorine, mg/l[a] 10 min	20 min	30 min	Chlorine demand mg/l
Treated water[b]	11	2.2	1.8	1.6	4.0
	11	2.0	1.5-2.0	2.0	3.6
	12	3.55	3.48	3.0	2.6
	12	3.0-4.0	3.0-4.0	3.0	2.6
	13	3.5	3.54	3.0	2.6
	13	3.0	3.0-34.0	4.0	1.6
	14	3.95	3.72	3.6	2.0
	14	3.0-4.0	4.0	3.0	2.6
	15	3.3	3.14	3.1	2.5
	15	3.0	3.0	3.0	2.6
	16	2.8	2.94	2.94	2.7
	16	3.0	2.5-3.0	2.5	3.1
Average chlorine demand					2.7
Std. dev.					0.636
Tapwater		6.45	6.2	6.2	0
		5.0-6.0	5.0-6.0	5.0-6.0	0

a. Stock solution (0.6 mL) was added to each sample, yielding an actual dose of 5.6 mg/l.
b. For each sample pair the first determination of chlorine demand was by means of the Fisher-Porter titrator and the second by use of the DPD method.

APPENDIX B: GLOSSARY OF TERMS

CFU	colony forming units
COD	chemical oxygen demand
DPD	N,N-diethyl-p-phenylenediamine
FAC	free available chlorine
GC/MS	gas chromatography/mass spectrometry
gph	gallons per hour
gpm	gallons per minute
NTU	nephelometric turbidity units
MERDC	Mobility Equipment Research and Development Center
PAC	powdered activated carbon
rpm	revolutions per minute
TDS	total dissolved solids
TS	total solids
TOC	total organic carbon
USABRDL	U.S. Army Biomedical Research and Development Laboratory
USACERL	U.S. Army Construction Engineering Research Laboratory
VMI	Virginia Military Institute

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